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MEMORANDUM REPORT ARBRL-MR-02943

MEASURED CARBON FIBER EXPOSURES TO MALFUNCTION FOR CIVILIAN ELECTRONIC ITEMS

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March 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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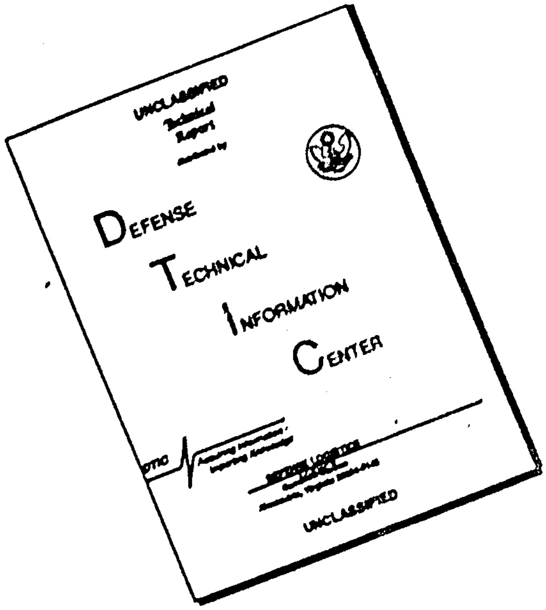

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A sample of 24 items was selected to represent the large population of electronic items found in the home and office. These were exposed to airborne carbon fibers until malfunctions developed or until high exposure levels were reached. The resulting mean exposures to malfunction are to be used to estimate the hazard presented by carbon fibers accidentally released by civilian aircraft crashes.

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I. INTRODUCTION

Carbon fibers are electrically conductive and, because of the fiber's small diameter of about 10 micrometers and light weight, travel through the air in the manner of large dust particles. Airborne carbon fibers which enter the cases of electrical or electronic equipment have been observed in some instances to bridge gaps and cause some items to malfunction. These malfunctions result from shorts or arcs and in some cases electrical or electronic damage is produced.

The use of carbon fibers in high strength composite materials is increasing each year. Among other uses, the application of composite materials as high strength and high stiffness-to-weight ratio components of aircraft is expected to increase significantly in the 1980's.

In structural applications the carbon fibers are bound with epoxy or other binders which do not allow the individual carbon fibers to become airborne. However, should an aircraft be involved in a fire, the individual carbon fibers may be freed from the matrix and released into the air.

The magnitude of the hazard to electrical and electronic equipment resulting from accidental release of fibers from civil aircraft crashes is to be evaluated under the NASA Graphite Fiber Risk Assessment Program. This program involves the participation of several governmental organizations and contractors under the technical coordination of NASA, Langley Research Center, Hampton, Virginia.

A complete risk analysis requires projected data on the weight of carbon fibers in use, the incidence of air crashes, the probable percentage by weight of carbon fiber released into the air by an accident, the distribution of lengths released, the transport of airborne fibers, the density of items in the impacted region, the penetration factors into buildings, the probabilities of producing malfunctions among exposed items, and the consequences in terms of dollars lost caused by these malfunctions.

As required by the risk analysis, several electrical and electronic items often found in the office or the home were tested to yield exposure data. The items were placed in a test chamber, exposed to carbon fibers and any malfunctions described.

Exposure is defined as

$$E = \int_0^t C(t) \quad dt \qquad (1)$$

where C is the concentration of carbon fibers suspended in the air (fibers/meter^3). The concentration of interest here is located just outside the item's case.

For each malfunctioning item the exposure corresponding to the time of malfunction was measured.

II. THE EXPONENTIAL MODEL OF FAILURE AND USE OF THE DATA

To calculate the incidence of item malfunctions the mean exposure to malfunction, $\langle E_o \rangle$, resulting from these tests, can be used with the Exponential Model of Failure. The method used to estimate the mean of the assumed exponential failure distribution can be found in Appendix A.

The Exponential Model of Failure relates exposure and probability of malfunction whenever the observed malfunctions result from a single fiber acting independently. This in turn implies that the fiber producing the malfunction is longer than the electrical gap spacing at which the fault occurs.

Calculation of the actual number of items malfunctioning in a real accidental release requires a model with many inputs as listed earlier. However, to illustrate how the data are used, we give the following simplified example. For a given length fiber the probability of an item malfunctioning when exposed to any exposure, E, of that length is

$$P\ (E) = 1 - e^{-\frac{E}{\langle E_o \rangle}} \qquad (2)$$

where P = probability of malfunction

E = exposure outside the item

$\langle E_o \rangle$ = mean exposure to malfunction for the item (measured or estimated)

If E is much less then $\langle E_o \rangle$ (as is expected in accidental release exposures over wide areas) then expanding yields

$$P\ (E) = 1 - \left[1 - \frac{E}{\langle E_o \rangle} + \left(\frac{E}{\langle E_o \rangle} \right)^2 + \cdots \right] \qquad (3)$$

$$P\ (E) \approx \frac{E}{\langle E_o \rangle}, \text{ if } E \ll \langle E_o \rangle \qquad (4)$$

For a number of similar items, N_o, which can be characterized by mean exposure to malfunction $\langle E_o \rangle$ and are impacted by approximately the same exposure level E, the number malfunctioning N_m is

$$N_m \cong \frac{E}{\langle E_o \rangle} N_o \quad , \text{ for } \quad E \ll \langle E_o \rangle \qquad (5)$$

If we assume fiber exposures reach 10^3 fibers·seconds/m^3 (f·s/m^3) and the items have mean exposures of 10^6 f·s/m^3 then

$$N_m \cong \frac{10^3 \text{ f}\cdot\text{s/m}^3}{10^6 \text{ f}\cdot\text{s/m}^3} N_o \cong \frac{N_o}{1000} \qquad (6)$$

One out of a thousand such items would malfunction if 10^3 f·s/m^3 were the exposure measured outside the item cases. (Most mean exposures $\langle E_o \rangle$ for items here reported are greater than 10^7 f·s/m^3.)

Estimates similar to the above are needed for each fiber length arriving at the item. Also, E and $\langle E_o \rangle$ as discussed in this report pertain to the location just outside the item's case and a building transfer function must, therefore, be applied to outdoor exposure to find the indoor exposure. Currently this factor must be estimated. (The indoor exposure may range from 1 to 10^{-4} of outdoor exposure depending mostly upon how open the doors and windows of a building are.)

III. TEST DESCRIPTION

A. Test Objectives

To expose a sample of civilian electronics items to carbon fibers of given length, note any malfuntion, and measure the corresponding exposure outside the item.

The mean exposures to malfunction are presented here as an estimate. The accuracy of which is well within an order of magnitude.

B. Selection of Items

To estimate the projected incidence of malfunctions among civilian electronics, a sample of home and office electronics were selected.

For home electronics, categories were selected in which the investments of dollars is largest.[1]

[1] *Home Electronic Testing - Category Selection*, letter from Fred Phillips, Bionetics, Inc., March 1978.

The categories were selected by consulting 1977 sales volume data in Merchandise Magazine.[2] Table I summarizes the important categories and the number of items chosen to sample each category.

TABLE I - HOME ELECTRONIC CATEGORIES & ITEMS TESTED

Category	1977 Sales Volume	Number of Items Tested
Phonographs: Portable and Table	$585 Million	1
Radios: Portable	616	1
Clock	480	1
TV's: Black & White	651	2
Color	4438	2
Audio: Receivers	392	1
Turntables	252	-
Cartridges	81	-
Speakers	416	-
Compact System: With 8-track or cassette	772	1
Portable Tape: With cassette	462	2
Electronic Calculators: Hand-held	412	1
Electronic Printer	300	1
Digital Watches: (Sealed Case)	686	-
	$10,543 Million	12

$$\frac{\text{Total, above categories}}{\text{Total, 1977 sales}} = \frac{\$10,543}{\$12,212} = 0.87$$

These categories accounted for 87% of all dollars spent on home electronics in 1977.

[2] *Merchandise Magazine, March 1978.*

Within the named categories specific models were chosen without pre-examination to determine how generic the model was or how vulnerable it might be to carbon fibers. Since these models were purchased mostly in 1978, the sample should be representative of technology in use in the 1980's. This selection rationale is named *"Many Dollars Invested"*. If no sales data were available on the item but many dollars were assumed invested in the category, we add *"(Assumed)"*.

Several items were chosen because examination indicated they were similar in ventilation, operating voltages, electronics, etc., to other items. This selection rationale is named *"Generic"*.

Another selection rationale was used to choose the LSI-11 computer and Dynaco amplifier. These items were judged likely to malfunction because of **ventilation, power available, and gap spacing.** The LSI-11 and Dynaco amplifier both are fan-cooled without filters. (The Dynaco amplifier appears similar in electronic construction to industrial servo amplifiers.) The LSI-11 has many gaps which are less than one millimeter separation. This selection rationale is called *"Likely to Fail"*.

Table II lists the items by model number and indicates the selection rationale. The selection rationale is also incorporated into Appendix II, Test Notes Specific To Items.

For anyone using the mean exposures to malfunction measured for these items to estimate the mean exposures to malfunction characteristic of similar electronics in the USA, careful consideration must be given to how the items were chosen. In particular, mean exposures for *"Likely To Fail"* items should be used only to estimate mean exposure for items with similar **ventilation, gap spacing,** power, and etc.

Other items were considered or examined as candidates for the sample but because of their characteristics - usually ventilation, which greatly restricts the intake of dust - were considered so unlikely to malfunction that they were not purchased for test. These included all lighting fixtures, digital watches, vacuum cleaners, industrial process controlers (almost always in dust tight cases), clocks, walkie-talkie radios, and automotive ignitions.

C. Exposure Chamber

The test chamber is fabricated of glass and aluminum panels supported by an aluminum angle frame. The aluminum parts are painted with white epoxy paint. The inside dimensions are 1.2 x 1.2 x 1.4 meters.

In a real accidental exposure, items would be located in buildings some distance from windows or other openings through which fibers enter. Air flow patterns and carbon fiber fall velocity would produce an exposure map for each room with exposure decreasing by orders of magnitude over exposure just inside the openings to the outside. Generally, items are located near walls. They experience some airflow including self-generated air flow from convective cooling. These facts tend to make the expected concentration very non-homogeneous for real exposures.

Our small test chamber is not ideally homogeneous in concentration so that when two ball detectors are placed around an item, the two ball exposures may differ occasionally by as much as a factor of 6 or 8. The run exposures presented (E_1) are either the average of two detectors placed around an item or that read by the closer ball.

D. Fiber Feed System

The dispensing system is a modified form of a Mitre Corporation design. It consists of a vertical tube with the following sections (starting from the bottom): fan, screen, vertical funnel section, cylindrical tube section, and output spout. Precut fibers are loaded into the funnel onto a screen just above the fan. The fan output is adjusted until - in the narrow part of the funnel - the air velocity bounces the clumps, while in the cylindrical section the low air velocity is just adequate to levitate single fibers, but not heavier clumps. Finally the fibers go through a constricting output spout which again increases the air velocity to minimize fiber-wall sticking. In addition, a timed pulse of high pressure air is applied inside the tube to aid de-clumping.

E. Fibers

1. Materials. Fibers were chosen which are widely used and which have no surface contaminants since fibers released from an aircraft fire are expected to be cleaned by the heat. (Any subsequent redeposit of airborne contaminants such as soot is not considered here.)

Usually, fiber manufacturers supply fibers which have been surface-treated to prevent fraying during handling. These surface treatments usually utilize polyvinyl alcohol, but some manufacturers do not divulge the chemical they apply. (The treatment and chemical itself are spoken of as "sizing".)

Thornel 300 was chosen because it was widely used in 1978. Thornel 300 has a resistance per centimeter of 7 kilohms.

NASA Langley Research Center supplied us with two forms of Thornel 300:

a. Thornel 300 "unsized" - This fiber was heat-treated by NASA to remove the manufacturer's sizing. A mass spectrometer was used to confirm that the treatment had been removed.

b. Thornel 300 H_2O sized - This material was water treated by the manufacturer. The water was assumed no longer present at the time the fibers were dispensed.

While most of the tests reported here were performed with the above fibers, in some earlier testing, data for which is included here, HMS, AS, or other fibers as listed in the data tables were dispensed. Where no sizing information appears in the tables, the fiber should be considered sized with the manufacturer's proprietary chemical.

2. Lengths. Fibers longer than 3 millimeters were cut to length with either a butcher knife or bandsaw. The bandsaw cuts a bundle of about 4 million fibers held together by string and tape. The bandsaw technique produces "muffins" which yield fibers with very small length variation.

Fibers shorter than 3 millimeters were cut using a butcher knife. This process results in lengths within 1/2 millimeter of the attempted length, e.g., 2-3 millimeter fibers result when attempting to cut 2.5 millimeters.

3. "Sticky Paper" Samplers For Length Distribution and Deposition.

"Sticky Papers," consisting of 4 centimeter squares of clear acetate with adhesive on one side, were placed around and inside some test items. These samplers allow the fiber lengths to be measured for fiber length distribution. These samplers were frequently used to check cutting accuracy.

In addition, the fibers may be counted for deposition (fibers/meter^2).

For very low air velocities the exposure is related to deposition on "sticky paper" by

$$D = E \cdot V_f \tag{7}$$

D = deposition on horizontal surface (fibers/meter^2)

E = exposure above surface (fiber·seconds/meter^3)

V_f = fall velocity of individual fibers $\sim$ 0.03 meter/second

F. Ball Detector for Monitoring Fiber Concentration

The ball detector is a conducting sphere which is maintained at 2000 volts. In still air the ball attracts and counts the fibers by the charge each fiber receives when it impacts on the ball. The number of fibers impacting on the ball per second is proportional to fiber concentration and, therefore, allows calibration against concentrations measured by other techniques.[3]

Counts from the ball are recorded on a multi-channel analyzer which advances one channel every sampling time interval (usually 10 seconds/channel.) The counts versus time are read out on paper tape. The tape and calibration parameters such as fiber length and air velocity are entered into a Hewlett-Packard 9830A computer. The computer produces plots and tables of concentration and exposure as a function of time.

The time of item malfunction is used with the exposure as a function of time plot to arrive at the exposure, E_i, which corresponds to the malfunction. If the item did not malfunction, the run was terminated at a high level, E_i, and "($>E_i$)" was entered in the table. No attempt was made to correlate concentration with malfunction.

G. "Wire" Detector for Monitoring Short Fiber Concentration

The ball detector yields an output pulse height which decreases with fiber length. A one millimeter fiber yields about a one millivolt pulse with the calibrated ball/electronics. Attempts to measure concentrations of one millimeter fibers were not successful because the pulse height discriminator whenever set at less than one millivolt was unable to exclude noise from the counting system.

To measure concentrations of one millimeter fibers a "wire" detector* was calibrated. The calibrated wire had dimensions of about 1.5 x 160 millimeters, was maintained at 1500 volts and shielded by a grounded can. Sticky paper depositions were used to measure the exposure against which the wire counts were calibrated.

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[3] *John A. Morrissey, William I. Brannan, and Samuel C. Thompson, "Calibration BRL Ball and Sticky Cylinder Detector System", Ballistic Research Laboratory, Technical Report ARBRL-TR-02079, Jun 78. (AD #B029204L)*

* *Fred Phillips and Israel Taback, Bionetics Inc., reported observations of wire pulse heights of tens of millivolts for one millimeter fibers.*

The pulse height produced by this wire detector was about 15 millivolts for one millimeter fiber impacts.

Exposure data for fibers of 2 millimeters or less were measured with the wire detector.

H. Typical Concentration/ Exposure History

Figure 1 is a typical plot of concentration and exposure as a function of time.

The concentration levels at which most of the exposures were made range from 10^3 to 10^5 f/m^3 for fibers around 7 millimeters long and 5×10^3 to 5×10^5 f/m^3 for fibers less than 3 millimeters long.

The maximum exposure reached in some of the tests was limited to about 3×10^7 f·s/m^3. First, because insignificant dollar losses are expected from low cost items (the malfunction of which is inconsequential) which have mean exposures above, say, 1×10^7 f·s/m^3. Second, when exposures above 10^7 f·s/m^3 are applied fibers begin to lie upon one another and thereby reduce the likelihood that newly arriving fibers will penetrate item cases. This is more important for convectively cooled items ventilated by top, horizontal, slots as were many of the test items. Slots under items or on the vertical side of an item are not as subject to fiber "self-filtering" so that some runs were continued to levels above 1×10^8 f·s/m^3. "Self-filtering" decreases the incremental failure probability per exposure increment at higher exposure levels.

I. Item Operation Mode During and After Exposure

When exposed in realistic scenarios items would be found *OFF* or operating in a given mode. For example, the Onkyo Receiver could be *OFF*, operating *FM*, *AM*, *TAPE*, etc.

Items exposed while operating were here observed to malfunction at lower exposures than items *OFF* during exposure (and operated afterward). Nevertheless, since most items are usually found *OFF* much more often than *ON*, the *OFF* mode incidence of malfunction could be as significant.

For *ON* testing of multimode items one mode was selected which utilizes several electronic subassemblies. The item was exposed and after exposure all other switch-selectable operation modes were checked. For *OFF* mode testing, the item was exposed to a high level while *OFF*. The operation of all modes was checked after exposure.

Selected operating modes are described in Appendix II, Test Notes Specific to Items.

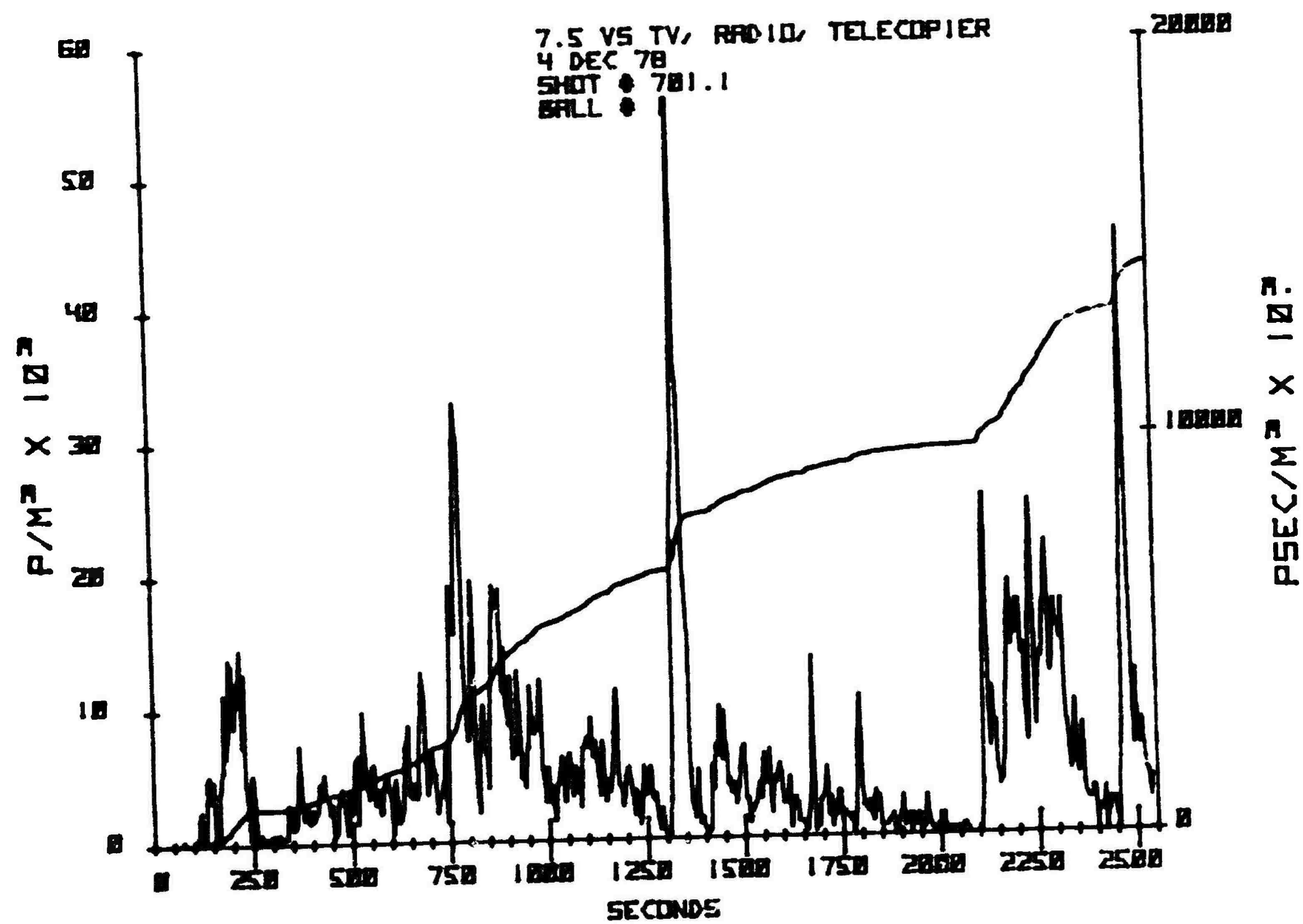

Figure 1. Typical Plot of Concentration and Exposure as a Function of Time

J. Test Procedure

1. From one to four items were placed together in the test chamber.

2. Items were checked out by operating for times long compared to the test duration.

3. Items were placed in the operation modes selected for testing.

4. Carbon fibers were dispensed.

5. a. When the first item malfunctioned the fiber dispenser and ball recorder were stopped.

b. OR when a high level exposure was reached, say, $E > 2 \times 10^7$ $f \cdot s/m^3$, the exposure was terminated.

6. AC power was removed from the malfunctioning item and reapplied to see if this cleared the malfunction.

7. All switch-selectable operation modes on all other items were checked.

8. The chamber and items were vacuumed. The inside of the case of the malfunctioning item was vacuumed. (This usually cleared the malfunction.) The inside of items which did not malfunction may or may not have been vacuumed depending on whether opening the case seemed likely to place more fibers inside the case than would be cleaned out.

9. Items were repaired if necessary and placed back in the chamber for check out and re-testing.

K. Damage Extent and Repairs

Most malfunctions were cleared by simply vacuuming the inside of the item. Only 6 of 98 observed malfunctions required repair, and 2 of those were with the Dynaco Amplifier.

The extent of damage and repair cost may be estimated by noting the nature of the repair. Each repair is described in Appendix B. Test Notes Specific to Items.

IV. RESULTS - DATA TABLES

The following tables are a summary of all the data pertaining to the vulnerability testing of civilian electronic items. Table III contains the results of all the vulnerability tests. Table IV is a summary of these tests and presents the measured $<E_o>$ for each tested item. Table V summarizes the failures obtained during the testing.

TABLE II. CATEGORIES, ITEMS AND SELECTION RATIONALE

CATEGORY-ITEM	DESCRIPTION	MANUFACTURER/ MARKETER	MODEL NO.	ELECTRONICS PRE EXAMINED	SELECTION RATIONALE
1. Amplifier	Audio, power	Dynaco	410	Yes	*Likely to Fail*
2. Calculator/ Printer	Programmable	Texas Instr.	SR56w/PC100	No	*Many Dollars Invested*
3. Computer	Micro	MOS Technology, Inc.	KIM-1	No	*Generic*
4. Computer	Mini	DEC/RDA, Inc.	LSI-11	Yes	*Likely to Fail*
5. Oven	Microwave	Amana	RR-9	No	*Many Dollars Invested (Assumed)*
6. Radio/Clock	Flip Display	Panasonic	RC-6010	No	*Many Dollars Invested*
7. Radio	Portable	General Electric	7-2971A	No	*Many Dollars Invested*
8. Receiver	AM-FM	Onkyo	TX-1500	No	*Many Dollars Invested*
9. Recorder	Port. Cassette	General Electric	3-5003-A	No	*Many Dollars Invested*
10. Recorder	Portable or AC	Marantz/Super-scope	C-104	No	*Many Dollars Invested*
11. Register, Cash	Memory	National Cash Register, Inc.	1921-112401	Yes	*Generic*
12. Stereo, System	"Compact"	Panasonic	SE1160	No	*Many Dollars Invested*
13. Telecopier	Telephone	Xerox	400	No	*Many Dollars Invested (Assumed)*
14. Terminal	Telephone	Texas Instr.	735	No	*Generic*
15. Terminal	Video	Lear Siegler, Inc.	ADM-3A	No	*Generic*

TABLE II. CATEGORIES, ITEMS AND SELECTION RATIONALE (CON'T)

CATEGORY-ITEM		DESCRIPTION	MANUFACTURER/ MARKETER	MODEL NO.	ELECTRONICS PRE EXAMINED	SELECTION RATIONALE
16.	Television	B&W, 16"	Sears	564.50360600	No	*Many Dollars Invested*
17.	Television	B&W, 19"	RCA	AC192W	No	*Many Dollars Invested*
18.	Television	Color, 19"	RCA	FB497W	No	*Many Dollars Invested*
19.	Television	Color, 25"	Sears/Sanyo	564.44580702	No	*Many Dollars Invested*
20.	Thermostat	Millivolt	Dayton	2E233	No	*Generic*
21.	Thermostat	24 Vac	Honeywell	T87F	No	*Generic*
22.	Thermostat	110 Vac	Dayton	2E369	No	*Generic*
23.	Valve	Millivolt	Dayton	36C21U	No	*Generic*
24.	Valve	24 Vac	Dayton	36C03	No	*Generic*

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_1) FOR ALL RUNS

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_1 f·s/m³	MALFUNCTION	REPAIR/CLEAN-UP
1. Amplifier Dynaco 410	1 (665)	T300 unsz	2.7	ON†	2.3×10^6	right channel to 0	Repair - see Test Notes
	2 (666)	"	"	"	5.5×10^6	left " " "	Vacuum clean
	3 (663)	"	2-3	"	1.2×10^6	" " " "	" "
	4 (664)	"	"	"	1.1×10^6	right " " "	" "
	5 (659)	"	7-8	"	2.7×10^5	" " " "	" "
	6 (660)	"	"	"	8.5×10^5	" " " ~40%	" "
	7 (661)	"	"	"	4.5×10^5	left " " ~50%	" "
	8 (662)	"	"	"	2.5×10^5	right " " 0	" "
	9 (667)	"	14.5	"	$\sim 1 \times 10^4$	left " " ~60%	" "
	10 (668)	"	"	"	1.8×10^4	both channels to ~60%	" "
	11 (669)	"	"	"	8.1×10^4	left channel to ~60%	" "
	12 (670)	"	"	"	1.6×10^4	" " " 0	Repair - see Test Notes

†Operation mode Input: 1000 Hz each channel; Output: ~48 Vac, 30-40 watts to light bulb loads.

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_1 f·s/m³	MALFUNCTION	REPAIR/CLEAN-UP
2. Calculator Printer Texas Inst. SR56/PC 100	1 (641)	AS	20	loop program	$>3.9 \times 10^7$	None	Inside Not Vacuumed
	2 (650)	T300 unsz	1.3	" "	$>2.6 \times 10^8$	"	" " "
	3 (651)	"	"	" "	$>2.0 \times 10^7$	"	" " "
	4 (652)	"	"	" "	$>1.5 \times 10^8$	"	" " "
	5 (653)	"	"	" "	$>1.6 \times 10^8$	"	" " "
	6 (648)	"	2.1	" "	$>1.6 \times 10^8$	"	" " "
	7 (649)	"	"	" "	$>1.9 \times 10^8$	"	" " "
	8 (642)	"	8	" "	$>7.5 \times 10^6$	"	" " "
	9 (643)	"	"	" "	$>1.7 \times 10^7$	"	" " "
	10 (644)	"	"	" "	$>2.2 \times 10^6$	"	" " "
	11 (645)	"	"	" "	$>5.4 \times 10^6$	"	" " "
	12 (646)	"	20	" "	$>2.5 \times 10^7$	"	" " "
	13 (647)	"	"	" "	$>7.5 \times 10^6$	"	" " "

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i f·s/m³	MALFUNCTION	REPAIR/CLEAN-UP
3. Computer, Micro MOS Technology KIM-1	1 (736)	3300 H_2Oxz	1.2 - 1.4	Digital Stopwatch(No cover)	>2.1 x 10^7	None	Vacuum
	2 (737)	" "	" "	" " "	+ >2.0 x 10^7	"	"
	3 (738)	" "	" "	" " "	>1.4 x 10^7	"	"
	4 (739)	" "	" "	" " "	>1 x 10^6	"	"
	5 (740)	" "	" "	" " "	+ >8.9 x 10^6	"	"
	6 (730)	" "	" 4.0	" " "	>3.7 x 10^7	"	"
	7 (731)	" "	"	" " "	>3.7 x 10^7	"	"
	8 (741)	" "	"	" " "	+ >8 x 10^5	"	"
	9 (742)	" "	"	as above, bottom side up	+ >4 x 10^5	"	"

+Post run - the computer is programmed a second time by magnetic tape.

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i f·s/m³	MALFUNCTION	REPAIR/CLEAN-UP
4. Computer, Mini DEC/RDA, Inc. LSI-11	1 (607)	HMS	1.0	ON, Memory Exerciser Program	9.6 x 10^6	No Output	Vacuum
	2 (608)	"	"	" " " "	1.6 x 10^6	Halt	"
	3 (609)	"	"	" " " "	1.7 x 10^7	Halt, erratic	"
	4 (610)	"	"	" " " "	3.6 x 10^6	" "	"
	5 (612)	"	"	" " " "	2.0 x 10^7	" "	"
	6 (613)	"	"	" " " "	1.9 x 10^6	" "	"
	7 (614)	"	"	" " " "	1.7 x 10^7	" "	"
	8 (615)	"	"	" " " "	6.0 x 10^5	"	"
	9 (616)	"	"	OFF-Post Run Load Program	4.9 x 10^8	"	"
	10 (617)	"	"	" " " "	1+ x 10^8 (2.6 x 10^6)*	"	"
	11 (618)	"	"	" " " "	1.9 x 10^8	"	"
	12 (600)	"	1.7	ON, Memory Exerciser Program	2.2 x 10^6	" , erratic	"
	13 (601)	"	"	" " " "	5.0 x 10^5	" "	"
	14 (602)	"	"	" " "	1.1 x 10^6	"	"
	15 (603)	"	"	" " " "	1.8 x 10^6	"	"
	16 (604)	"	"	" " " "	2.0 x 10^5	" , erratic	"
	17 (605)	"	"	" " " "	2.6 x 10^6	" , erratic	"
	18 (606)	"	"	" " " "	3.1 x 10^6	" "	"
	19 (620)	"	3.5	OFF-Post Run Loading	2.9 x 10^7 (2.1 x 10^5)*	" , recovery	"
	20 (561)	"	4.7	ON, Memory Exerciser Program	8.5 x 10^5	" , error, no recovery	"
	21 (562)	"	"	" " " "	7.2 x 10^5	" , no error, recovery	"
	22 (563)	"	"	" " " "	2.6 x 10^5	" , error, no recovery	"

* Exposure caused by LSI-11 fans after initial input exposure

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i f·s/m³	MALFUNCTION	REPAIR/CLEAN-UP
4. (Con't) Computer, Mini DEC/RDA, Inc. LSI-11	23 (564)	MMS	4.7	ON, Memory Exorciser Program	6.2×10^5	Halt, recovery	Vacuum
	24 (565)	"	"	" " " "	3.4×10^5	" , no recovery	"
	25 (551)	"	7.8	" " " "	8.4×10^4	" , error recovery	"
	26 (552)	"	"	" " " "	1.3×10^5	" , " "	"
	27 (553)	"	"	" " " "	6.1×10^5	" , no error	"
	28 (554)	"	"	" " " "	5.1×10^5	" , error, no recovery	"
	29 (555)	"	"	" " " "	1.5×10^5	" , error, no recovery	"
	30 (556)	"	"	" " " "	2.2×10^5	" , error, recovery	"
	31 (557)	"	"	" " " "	1.7×10^5	" , no error, no recovery	"
	32 (558)	"	"	" " " "	3.3×10^5	" , no error, no recovery	"
	33 (559)	"	"	" " " "	7.9×10^5	" , error, recovery	"
	34 (560)	"	"	" " " "	3.2×10^5	" , error, no recovery	"
	35 (618)	"	8	OFF, Programmed Post Run	$>1.5 \times 10^5$ (9.5×10^5)*	None	"
	36 (619)	"	"	" " " "	5.2×10^7 (2.3×10^6)*	Halt, no recovery	"
	37 (622)	"	"	" " " "	9.6×10^6 (5.0×10^5)*	Halt, no recovery	"
	38 (623)	"	"	" " " "	1.4×10^7 (2.6×10^5)*	Halt, no recovery	"
	39 (624)	"	"	" " " "	$>1.8 \times 10^6$ (2.3×10^5)*	None	"
	40 (625)	"	"	" " " "	7.0×10^5 (3.0×10^5)*	Halt, no recovery	"
	41 (626)	"	"	" " " "	5.8×10^6 (1.8×10^5)*	Halt, no recovery	"
	42 (627)	"	"	" " " "	4.9×10^5 (2.0×10^5)*	Halt, no recovery	"
	43 (628)	"	"	" " " "	$>2.0 \times 10^6$	None	"
	44 (629)	"	"	" " " "	8.3×10^6 (4.1×10^5)*	Halt, no recovery	"

*Exposure caused by LSI-11 fans after initial input exposure.

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f\cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
5. Oven Microwave Amana RR-9	1 (746)	3300 H_2Os:	[illegible]	OFF, clock on	2.3×10^7	None	Vacuum
	2 (747)	" "	"	" " "	$>5.8 \times 10^7$	"	"
	3 (743)	" "	4.0	" " "	$>5.8 \times 10^6$	"	"
	4 (744)	" "	"	" " "	$>2.2 \times 10^7$	"	"
	5 (745)	" "	"	" " "	$>1.8 \times 10^7$	"	"
	6 (748)	" "	"	ON/OFF, activated 2 times during exposure	$>5 \times 10^6$ - $<2 \times 10^7$	Countdown timer reset	"
	7 (749)	" "	"	ON/OFF, activated 6 times during exposure	$>1.8 \times 10^7$	Post Run-110Vac shock haz.	Vacuum
	8 (750)	" "	"	ON, Low Power, Fan On	6×10^6	Microwave on all the time to Hi (110Vac on switch)	Vacuum
	9 (751)	" "	10	" " " " "	6.6×10^6	Countdown timer stopped	High voltage transformer
6. Radio, clock Panasonic RC-6010	1 (687)	" "	2-3	ON, FM	$>5.5 \times 10^7$	None	Inside not vacuumed
	2 (688)	" "	"	" "	$>6.1 \times 10^7$	"	" " "
	3 (689)	" "	"	" "	$>3.8 \times 10^7$	"	" " "
	4 (697)	" "	"	" "	$>4.6 \times 10^7$	"	" " "
	5 (690)	" "	"	OFF, clock on	$>3.8 \times 10^7$	"	" " "
	6 (691)	" "	"	" " "	$>4.5 \times 10^7$	"	" " "
	7 (696)	" "	"	" " "	$>3.5 \times 10^7$	"	" " "
	8 (698)	" "	"	" " "	$>6.4 \times 10^7$	"	" " "
	9 (706)	" "	"	" " "	$>5.5 \times 10^7$	"	" " "
	10 (707)	" "	"	" " "	$>9 \times 10^7$	"	" " "

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f \cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
6. (Con't) Radio, clock Panasonic RC-6010	11 (700)	T300 H_2Osz	7-8	ON, FM	$>1.9 \times 10^7$	None	Inside not vacuumed
	12 (701)	" "	"	" "	$>1.7 \times 10^7$	"	" " "
	13 (702)	" "	"	" "	$>3.8 \times 10^6$	"	" " "
	14 (699)	" "	"	OFF, clock on	$>4.1 \times 10^6$	"	" " "
	15 (703)	" "	"	" " "	$>3.1 \times 10^6$	"	" " "
	16 (704)	" "	"	" " "	$>3.6 \times 10^7$	"	" " "
	17 (705)	" "	"	" " "	$>4 \times 10^7$	"	" " "
	18 (692)	" "	15	" " "	$>1.8 \times 10^7$	"	" " "
	19 (693)	" "	"	" " "	$>2.9 \times 10^7$	"	" " "
	20 (694)	" "	"	" " "	$>4 \times 10^7$	"	" " "
	21 (695)	" "	"	" " "	$>2.8 \times 10^7$	"	" " "
7. Radio, 10 Band Portable General Electric 7-2971	1 (674)	T300 unsz	2-3	ON, FM	$>4.0 \times 10^7$	None	Inside Not Vacuumed
	2 (675)	" "	"	" "	$>7.5 \times 10^7$	"	" " "
	3 (676)	" "	"	" "	$>8.0 \times 10^7$	"	" " "
	4 (656)	" "	7-8	" "	$>6.5 \times 10^7$	"	" " "
	5 (657)	" "	"	" "	$>2.2 \times 10^7$	"	" " "
	6 (658)	" "	"	" "	$>2.7 \times 10^7$	"	" " "
	7 (654)	" "	"	OFF	$>3.0 \times 10^7$	"	" " "
	8 (655)	" "	"	"	$>3.4 \times 10^7$	"	" " "
	9 (671)	" "	15	ON, FM	$>3 \times 10^7$	"	" " "
	10 (672)	" "	"	" "	$>1.9 \times 10^7$	"	" " "
	11 (673)	" "	"	" "	$>2.6 \times 10^7$	"	" " "
8. Receiver, AM-FM Onkyo TX 1500	1 (674)	T300 unsz	2-3	ON, FM Stereo	$>5.2 \times 10^7$	None	Vacuum
	2 (675)	" "	"	" " "	$>7.5 \times 10^7$	"	"
	3 (676)	" "	"	" " "	$>8.0 \times 10^7$	"	"
	4 (654)	" "	7-8	" " "	2.7×10^7	Loss Audio	"
	5 (655)	" "	"	" " "	$>3.4 \times 10^7$	None	"
	6 (656)	" "	"	" " "	$>6.5 \times 10^7$	"	"
	7 (651)	" "	"	" " "	$>3.5 \times 10^7$	"	"
	8 (658)	" "	"	" " "	$>3.4 \times 10^7$	"	"
	9 (671)	" "	15	" " "	$>2.2 \times 10^7$	"	"
	10 (672)	" "	"	" " "	$>1.9 \times 10^7$	"	"
	11 (673)	" "	"	" " "	$>2.6 \times 10^7$	"	"

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i f·s/m³	MALFUNCTION	REPAIR /CLEAN-UP
9. Recorder	1 (675)	T300 unsz	2-3	ON, Record to OFF	>7.5 x 10^7	None	Inside Not Vacuumed
Battery powered	2 (676)	" "	"	" " " "	>8 x 10^7	"	" " "
General Electric	3 (667)	T300 H.Os:	"	" " " "	>3.8 x 10^7	"	" " "
1-5003-A	4 (668)	" "	"	" " " "	>9.8 x 10^7	"	" " "
	5 (677)	" "	7-6	" " " "	>5.2 x 10^7	"	" " "
	6 (678)	" "	"	" " " "	>4.4 x 10^7	"	" " "
	7 (679)	"	"	" " " "	>4.9 x 10^7	"	" " "
	8 (680)		"	" " " "	>5.0 x 10^7	"	" " "
	9 (681)	"	"	OFF	>5.3 x 10^7	"	" " "
	10 (682)	" "	"	"	>3 x 10^7	"	" " "
	11 (683)	" "	14-15	"	>5.1 x 10^7	"	" " "
	12 (684)	" "	"	"	>3.4 x 10^7	"	" " "
	13 (685)	" "	"	"	>2.2 x 10^7	"	" " "
	14 (686)	" "	"	"	>2 x 10^7	"	" " "
10. Recorder, AC or Battery	1 (674)	T300 unsz	2-3	ON, Record to OFF	>4.0 x 10^7	Speed? (Temporary slow running)	Inside Not Vacuumed
Marantz/Super-scope C-104	2 (675)	T300 unsz	2-3	On, Record to OFF	>7.5 x 10^7	None	" " "
	3 (676)	" "	"	" " " "	>8 x 10^7	"	" " "
	4 (656)	" "	7-8	" " " "	>6.5 x 10^7	"	" " "
	5 (657)	" "	"	" " " "	>2.2 x 10^7	"	" " "
	6 (658)	" "	"	" " " "	>2.7 x 10^7	"	" " "
	7 (671)	" "	~15	" " " "	>3 x 10^7	Speed? (Temporary slow running)	" " "
	8 (672)	T300 unsz	~15	ON, Record to OFF	>1.9 x 10^7	None	Inside Not Vacuumed
	9 (673)	" "	"	" " " "	>2.6 x 10^7	"	" " "
11. Register, Cash National Cash Register 7321-112401	1 (687)	T300 H.Os:	2-3	ON/Memory	>5.5 x 10^7	None	Inside Not Vacuumed
	2 (688)	" "	"	" "	>6.1 x 10^7	"	" " "
	3 (677)	" "	7-8	ON	>5.2 x 10^7	"	" " "
	4 (678)	" "	"	"	>2.7 x 10^7	"	" " "
	5 (679)	" "	"	"	>2.9 x 10^7	"	" " "

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f \cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
11. (Con't) Register National Cash Register 1921-1:2401	6 (680)	T300 H_2Os:	7-8	ON	>3.2 x 10^7	None	Inside Not Vacuumed
	7 (681)	" "	"	Overnight Standby	>3.0 x 10^7	"	" " "
	8 (682)	" "	"	" "	>7.6 x 10^6	"	" " "
	9 (683)	" "	15	ON	>3.9 x 10^7	"	" " "
	10 (684)	" "	"	"	>2.4 x 10^7	"	" " "
	11 (685)	" "	"	ON /Memory	>2.2 x 10^7	"	" " "
	12 (686)	" "	"	" "	>1.6 x 10^7	"	" " "
12 Stereo System "Compact" Panasonic SE1160	1 (674)	T300 uns:	2-3	ON, FM Stereo	>6.5 x 10^7	None	Inside Not Vacuumed
	2 (675)	" "	"	" " "	>7.5 x 10^7	"	" " "
	3 (676)	" "	"	" " "	>8.0 x 10^7	"	" " "
	4 (654)	" "	7-8	" " "	>3.5 x 10^7	"	" " "
	5 (655)	" "	"	" " "	>3.4 x 10^7	"	" " "
	6 (656)	" "	"	" " "	>6.5 x 10^7	"	" " "
	7 (657)	" "	"	" " "	>4.8 x 10^7	"	" " "
	8 (658)	" "	"	" " "	>4.2 x 10^7	"	" " "
	9 (671)	" "	~15	" " "	>2.2 x 10^7	"	" " "
	10 (672)	" "	"	" " "	>1.9 x 10^7	"	" " "
	11 (673)	" "		" " "	>2.6 x 10^7	"	" " "
13. Telecopier Xerox 400	1 (696)	T300 H_2Os:	2-3	OFF	>3.5 x 10^7	None	Inside Not Vacuumed
	2 (697)	" "	"	"	>4.6 x 10^7	"	" " "
	3 (698)	" "	"	"	>3.7 x 10^6	"	" " "
	4 (699)	" "	7-8	"	>4.1 x 10^7	"	" " "
	5 (700)	" "	"	"	>1.9 x 10^7	"	" " "
	6 (701)	" "	"	"	>1.7 x 10^7	"	" " "
	7 (694)	" "	~15	"	>4 x 10^7	"	" " "
	8 (695)	" "	"	"	>2.8 x 10^7	"	" " "

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f \cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
14. Television	1 (708)	T300 H_2Osz	~1	OFF	$>5.3 \times 10^7$	None	Inside Vacuumed
B&W, 19"	2 (709)	" "	"	"	$>1.1 \times 10^8$	"	" "
RCA	3 (710)	" "	"	"	$>7 \times 10^7$	"	" "
AC 192W	4 (696)	" "	2-3	ON	3.5×10^7	Loss Vertical Deflection	" "
	5 (697)	" "	"	"	4.6×10^7	" " "	" "
	6 (698)	" "	"	"	6.4×10^7	Blank Off - Video & Audio	" "
	7 (706)	" "	"	OFF	$>5.5 \times 10^7$	None	" "
	8 (707)	" "	"	"	$>9.0 \times 10^7$	"	" "
	9 (699)	" "	7-8	ON	4.1×10^6	Loss Vertical Deflection	" "
	10 (700)	" "	"	"	1.9×10^7	" " "	" "
	11 (701)	" "	"	"	1.7×10^7	" " "	" "
	12 (702)	" "	"	"	3.8×10^6	" " "	" "
	13 (703)	" "	"	OFF	$>3.1 \times 10^7$	None	" "
	14 (704)	" "	"	"	$>3.6 \times 10^7$	"	" "
	15 (705)	" "	"	"	$>4 \times 10^7$	"	" "
	16 (694)	" "	~16	ON	$>4.0 \times 10^7$	"	" "
	17 (695)	" "	"	"	$>2.8 \times 10^7$	"	" "
15. Television	1 (524)	HMS sz	3.5	ON	$>4.3 \times 10^6$	None	Vacuum
B&W, 16"	2 (525)	" "	"	OFF	$>5.9 \times 10^7$	"	"
Sears	3 (520)	" "	~7	ON	$>2 \times 10^7$	"	"
564.50360600	4 (521)	" "	"	"	$>3.5 \times 10^7$	"	"
	5 (522)	" "	"	"	$>4.1 \times 10^7$	"	"
	6 (523)	" "	"	OFF	$>1.8 \times 10^7$	"	"
	7 (526)	" "	"	ON, Back Cover Removed	$>4.2 \times 10^7$	"	"
	8						
16. Television	1 (687)	T300 H_2Osz	2-3	ON	$>5.5 \times 10^7$	None	Inside Not Vacuumed
Color, 25"	2 (688)	" "	"	"	6.1×10^7	Loss Horizontal Control	Vacuum
Console	3 (677)	" "	7-8	"	$>3.6 \times 10^7$	None	Inside Not Vacuumed
Sears	4 (678)	" "	"	"	$>2.7 \times 10^7$	"	" " "
564.44580702	5 (679)	" "	"	"	$>2.9 \times 10^7$	"	" " "
	6 (680)	" "	"	"	$>3.2 \times 10^7$	"	" " "
	7 (681)	" "	"	OFF	$>3.0 \times 10^7$	"	" " "
	8 (682)	" "	"	"	$>3.1 \times 10^7$	"	" " "
	9 (683)	" "	15	ON	3.9×10^7	Function OK, but burned odor	Vacuum & replace resistor
	10 (684)	T300 H_2Osz	15	ON	$>2.4 \times 10^7$	None	Inside Not Vacuumed

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f\cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
16. (Con'T) Television Color, 25" Console Sears 564.44580702	11 (685)	T300 H_2Osz	15	ON	2.2×10^7	Blue Gun Full On	Vacuum
	12 (686)	" "	"	"	$>1.6 \times 10^7$	None	Inside Not Vacuumed
17. Television, Color, 19" Portable, RCA FB497W	1 (640)	AS sz	20	ON	$>2.7 \times 10^7$	None	Vacuum
	2 (641)	" "	"	"	3.9×10^7	Loss Vertical Deflection	"
	3 (630)	HMS sz	8	"	4.3×10^6	" " "	"
	4 (631)	" "	"	"	4.6×10^7	" " "	"
	5 (632)	" "	"	"	1.2×10^7	" " "	"
	6 (633)	" "	"	"	4.1×10^6	" " "	"
	7 (634)	" "	"	"	9.5×10^5	" " "	"
	8 (636)	T300 sz	"	"	2.8×10^7	" " "	"
	9 (637)	" "	"	"	2.0×10^7	" " "	"
	10 (638)	" "	"	"	1.4×10^7	" " "	"
	11 (639)	" "	"	"	$>7.8 \times 10^7$	None	"
	12 (635)	" "	20	"	$>3.9 \times 10^5$	"	"
	13 (646)	" "	"	"	2.5×10^7	Loss Vertical Deflection	"
	14 (650)	" unsz	1.3	"	$>2.6 \times 10^8$	None	"
	15 (651)	" "	"	"	2×10^7	Loss Vertical Deflection	"
	16 (652)	" "	"	"	$>1.5 \times 10^8$	None	"
	17 (653)	" "	"	"	$>1.6 \times 10^8$	"	"
	18 (648)	" "	2.1	"	1.6×10^8	Loss Vertical Deflection	"
	19 (649)	" "	"	"	1.9×10^8	" " "	"
	20 (642)	" "	8	"	7.5×10^6	" " "	"
	21 (643)	" "	"	"	1.7×10^7	" " "	"
	22 (644)	" "	"	"	2.2×10^6	" " "	"
	23 (645)	" "	"	"	5.4×10^6	" " "	"
	24 (647)	" "	20	"	7.5×10^6	" " "	"
	25 (768)	" H_2Osz	7.5	ON, Back Cover Removed	2.2×10^6	Loss Video	"
	26 (769)	" "	"	" " " "	1.3×10^6	" "	"
	27 (770)	" "	"	" " " "	6×10^5	" "	"
	28 (771)	" "	"	" " " "	7.6×10^5	" "	"
	29 (772)	" "	"	" " " "	1.2×10^6	" "	"

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f \cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
18. Terminal Computer Via Telephone Texas Instr. ~33	1 (738)	T300 H_2Osz	1.2-1.4	ON, Frequent Recall by Keying	1.4×10^7	Erratic or No Response To Keying	Vacuum
	2 (739)	T300 H_2Osz	1.2-1.4	ON, Frequent Recall by Keying	$~1 \times 10^6$	No Recall from Remote Computer	Vacuum & Blow
	3 (740)	T300 H_2Osz	1.2-1.4	ON, Frequent Recall by Keying	8.9×10^6	Carrier Light Off	" " "
	4 (741)	T300 H_2Osz	~4	ON, Frequent Recall by Keying	8×10^5	Print Random - (Carrier OK)	" " "
	5 (742)	T300 H_2Osz	~4	ON, Frequent Recall by Keying	2.5×10^6	Carrier Light Off	Imcomplete
19. Terminal Computer, Video Lear Siegler, Inc. ADM-3A	1 (746)	T300 H_2Osz	~1	ON, Writing & Scrolling	$>2.3 \times 10^7$	None	Inside Not Vacuumed
	2 (747)	" "	"	" " " "	$>5.8 \times 10^7$	"	" " "
	3 (743)	" "	4	" " " "	$>5.8 \times 10^7$	"	Vacuum
	4 (744)	" "	"	" " " "	$>2.2 \times 10^7$	"	"
	5 (745)	" "	"	" " " "	$>1.8 \times 10^7$	"	"
	6 (750)	" "	"	" " " "	$>6 \times 10^6$	"	Inside Not Vacuumed
	7 (748)	" "	"	OFF	$>2.5 \times 10^7$	"	" " "
	8 (749)	" "	"	"	$>1.8 \times 10^7$	"	" " "
	9 (751)	" "	10	ON, Writing & Scrolling	$>6.6 \times 10^6$	"	" " "
20. Thermostat Millivolt Dayten, 2E233	1 (500)	HMS sz	7	Temperature Switch Open	$>1.8 \times 10^7$	None	Inside Not Vacuumed
	2 (501)	" "	"	" " "	$>1.5 \times 10^7$	"	" " "
	3 (502)	" "	"	" " "	$>2.4 \times 10^7$	"	" " "
	4 (503)	" "	"	" " " (no case)	$>1.2 \times 10^7$	"	" " "

TABLE III. MALFUNCTIONS AND CORRESPONDING EXPOSURE LEVELS (E_i) FOR ALL RUNS (CON'T)

ITEM	TEST NO. (RUN NO.)	FIBER	LENGTH (MM)	ITEM OPERATION MODE	E_i $f \cdot s/m^3$	MALFUNCTION	REPAIR/CLEAN-UP
21. Thermostat 24 Vac Honeywell T87F	1 (500)	HMS sz	7	Temperature Switch Open	>1.8 x 10^7	None	Inside Not Vacuumed
	2 (501)	" "	"	" " "	>1.5 x 10^7	"	" " "
	3 (502)	" "	"	" " "	>2.4 x 10^7	"	" " "
	4 (503)	" "	"	" " "	>1.2 x 10^7	"	
22. Thermostat 120 Vac Dayton, 2E369	1 (500)	HMS sz	7	Temperature Switch Open	>1.8 x 10^7	None	Inside Not Vacuumed
	2 (501)	" "	"	" " "	>1.5 x 10^7	"	" " "
	3 (502)	" "	"	" " "	>2.4 x 10^7	"	" " "
	4 (503)	" "	"	" " "	>1.2 x 10^7	"	" " "
23. Valve, gas Millivolt Dayton 36C21U	1 (500)	HMS sz	7	Closed	>1.8 x 10^7	None	Inside Not Vacuumed
	2 (501)	" "	"	"	>1.5 x 10^7	"	" " "
	3 (502)	" "	"	"	>2.4 x 10^7	"	" " "
	4 (503)	" "	"	"	>1.2 x 10^7	"	" " "
24. Valve, gas 24 Vac Dayton 36C03	1 (500)	HMS sz	7	Closed (24 Vac through valve)	>1.8 x 10^7	None	Inside Not Vacuumed
	2 (501)	HMS sz	7	Closed (24 Vac through valve)	>1.5 x 10^7	None	Inside Not Vacuumed
	3 (502)	HMS sz	7	Closed (24 Vac through valve)	>2.4 x 10^7	None	Inside Not Vacuumed
	4 (503)	HMS sz	7	Closed (24 Vac through valve)	>1.2 x 10^7	None	Inside Not Vacuumed

TABLE IV. MEASURED MEAN EXPOSURES TO MALFUNCTION FOR EACH FIBER, FIBER LENGTH AND ITEM OPERATION MODE

Calculated by assuming malfunctions are related to exposure by the Exponential Failure Model:

$$<E_o> = \Sigma \frac{E_i}{m}$$

E_i = exposure reached when the item malfunctions or when carbon fiber dispensing is terminated.

m = number of malfunctions - we set m=1 for a series of exposures which do not produce an item malfunction.

	ITEM	FIBER	LENGTH (mm)	ITEM OPERATION MODE	NO. OF TESTS	$<E_o>$ $f \cdot s/m^3$
1.	Amplifier	T300 unsz	2-3	ON	4	2.5×10^6
	Audio Power	T300 unsz	7-8	ON	4	5×10^5
	DYNACO 410	T300 unsz	14-15	ON	4	3×10^4
2.	Calculator/	AS	20	ON, Loop Program	1	$> 3.9 \times 10^7$
	Printer	T300 unsz	1.3	ON, Loop Program	4	$> 5.9 \times 10^8$
	Tex. Inst.	T300 unsz	2.1	ON, Loop Program	2	$> 3.5 \times 10^8$
	SR56/PC100		8.0	ON, Loop Program	4	$> 3.2 \times 10^7$
			20	ON, Loop Program	2	$> 3.3 \times 10^7$
3.	Computer Micro	T300 H_2O sz	1.2-1.4	ON, Digital Stopwatch	2	$> 1.5 \times 10^7$
	MOS Technology KIM-1	T300 H_2O sz	1.2-1.4	ON, Digital Stopwatch plus programming by tape	3	$> 5.0 \times 10^7$
		T300 H_2O sz	4	ON, Digital Stopwatch plus	2	$> 7.4 \times 10^7$
		T300 H_2O sz	4	programming by tape	2	$> 1.2 \times 10^6$
4.	Computer, Mini	HMS	1	ON, Memory Diagnostic Program	9	8.9×10^6
	DEC/RDA, Inc	HMS	1	OFF	3	Est.* $> 1 \times 10^8$
	"LSI-11"	HMS	1.7	ON, Memory Diagnostic Program	7	1.6×10^6
			3.5	OFF	1	2.9×10^7
			4.7	ON, Memory Diagnostic Program	5	5.6×10^5
			7.8	ON, Memory Diagnostic Program	10	3.3×10^5
			8	OFF	10	Est.* 5×10^6

* Estimate from data

TABLE IV. MEASURED MEAN EXPOSURES TO MALFUNCTION FOR EACH FIBER, FIBER LENGTH AND ITEM OPERATION MODE (CON'T)

ITEM	FIBER	LENGTH (mm)	ITEM OPERATION MODE	NO. OF TESTS	$<E_o>$ $f \cdot s/m^3$
5. Oven, Microwave Amana	T300 H_2O sz	~1	OFF, clock on	2	> 8.1×10^7
	" " "	4	ON & OFF, activated at times during exposure	2 Estimate	> 5×10^6 < 2×10^7
RR-9	T300 H_2O sz	4	OFF, clock on	3	> 3.5×10^7
	" " "	4	ON, Low Power continuous	1	6×10^6
	" " "	10	" " " "	1	6.6×10^6
6. Radio, clock Panasonic RC-6010	T300 H_2O sz	2-3	FM	4	> 2.0×10^8
	" " "	2-3	OFF	6	> 3.2×10^8
	" " "	7-8	FM	3	> 4×10^7
	" " "	7-8	OFF	4	> 1.1×10^8
	" " "	15	OFF	4	> 1.1×10^8
7. Radio, portable General Electric 7-2971	T300 unsz	2-3	FM	3	> 1.9×10^8
	" "	7-8	FM	3	> 1.1×10^8
	" "	7-8	OFF	2	> 6.4×10^7
	" "	15	FM	3	> 7.5×10^7
8. Receiver, AM-FM Onkyo	T300 unsz	2-3	FM	3	> 2×10^8
	" "	7-8	FM	5	1.9×10^8
	" "	~15	FM	3	> 5.7×10^7
9. Recorder, Port. General Electric 3-5003-A	T300 H_2O sz	2-3	Record to OFF	2	> 1.3×10^8
	T300 unsz	2-3	" " "	2	> 1.5×10^8
	T300 H_2O sz	7-8	" " "	4	> 2×10^8
	" " "	7-8	OFF	2	> 8.3×10^7
	" " "	14-15	Record to OFF	4	> 1.2×10^8

TABLE IV. MEASURED MEAN EXPOSURES TO MALFUNCTION FOR EACH FIBER, FIBER LENGTH AND ITEM OPERATION MODE (CON'T)

ITEM	FIBER	LENGTH (mm)	ITEM OPERATION MODE	NO. OF TESTS	$<E_o>$ $f \cdot s/m^3$
10. Recorder, AC or Portable	T300 unsz	2-3	Record to OFF	3	> 7.5×10^7
Superscope' Marantz	T300 unsz	7-8	Record to OFF	3	> 1.1×10^8
C-104	T300 unsz	~15	Record to OFF	3	> 1.9×10^8
11. Register, cash	T300 H_2O sz	2-3	ON/Memory	2	> 1.1×10^8
Nat. Cash Reg.	" " "	7-8	ON	4	> 1.4×10^8
1912-112401	" " "	7-8	Overnight Standby	2	> 3.7×10^7
	" " "	15	ON	2	> 6.3×10^7
	" " "	15	ON/Memory	2	> 3.8×10^7
12. Stereo System "Compact"	T300 unsz	2-3	ON, FM Stereo	3	> 2.2×10^8
Panasonic	" "	7-8	ON, FM Stereo	5	> 2.2×10^8
SE 1160	" "	~15	ON, FM Stereo	3	> 5.7×10^7
13. Telecopier	T300 H_2O sz	2-3	OFF	3	> 1.1×10^8
Xerox	" " "	7-8	OFF	3	> 4×10^7
400	" " "	14-16	OFF	2	> 6.8×10^7
14. Television, B&W 16"	HMS	3.5	ON	1	> 4.3×10^6
Sears	HMS	3.5	OFF	1	> 5.9×10^7
	"	7	ON	3	> 9.6×10^7
	"	7	OFF	1	> 1.8×10^7
	"	7	ON, back cover removed	1	> 4.2×10^7

TABLE IV. MEASURED MEAN EXPOSURES TO MALFUNCTION FOR EACH FIBER, FIBER LENGTH AND ITEM OPERATION MODE (CON'T)

ITEM	FIBER	LENGTH (mm)	ITEM OPERATION MODE	NO. OF TESTS	$<E_o>$ $f \cdot s/m^3$
15. Television, B&W, 19"	T300 H_2O sz	~1	OFF	3	> 2.3×10^8
RCA	T300 H_2O sz	2-3	ON	3	4.8×10^7
AC 192W	" " "	2-3	OFF	2	> 1.4×10^8
	" " "	7-8	ON	4	1.1×10^7
	" " "	7-8	OFF	3	> 1.1×10^8
	" " "	~16	ON	2	> 6.8×10^7
16. Television, 19" Color	AS sized	20	ON	2	6.6×10^7
RCA	HMS sized	8	ON	5	6.7×10^6
FW 497W	T300 sized	8	ON	4	4.7×10^7
	" "	20	ON	1	> 3.9×10^5
	" unsized	1.3	ON	1	5.9×10^8
	" "	2.1	ON	2	> 3.5×10^8
	" "	8	ON	4	8.0×10^6
	" "	7.5	ON, back cover removed	5	1.2×10^6
17. Television, 25" Color	T300 H_2O sz	2-7	ON	2	1.1×10^8
Sears	" " "	7-8	ON	4	> 1.2×10^8
564.44580702	" " "	7-3	OFF	2	> 6.1×10^7
	" " "	15	ON	4	2.5×10^7
18. Terminal, Telephone Texas Inst. 735	T300 H_2O sz	1.2-1.4	ON-Frequent recall by keying	3	8×10^6
	" " "	~4	" " " " "	2	1.7×10^6

TABLE IV. MEASURED MEAN EXPOSURES TO MALFUNCTION FOR EACH FIBER, FIBER LENGTH AND ITEM OPERATION MODE (CON'T)

ITEM	FIBER	LENGTH (mm)	ITEM OPERATION MODE	NO. OF TESTS	$<E_o>$ f·s/m³
19. Terminal, Video Lear Siegler, Inc. ADM-3A	T300 H_2O sz	1	ON, writing and scrolling	2	> 8.1×10^7
	" " "	4	" " " "	4	> 5.1×10^7
	T300 H_2O sz	4	OFF	2	> 4.3×10^7
	" " "	10	ON, writing and scrolling	1	> 6.6×10^6
20. Thermostat, millivolt Dayton 2E233	HMS	7	OPEN,	3	> 5.7×10^7
	"	7	Open, No cover	1	> 1.2×10^7
21. Thermostat, 24Vac Honeywell T87F	HMS	7	OPEN, 24vac applied	3	> 5.7×10^7
	"	7	" " " No cover	1	> 1.2×10^7
22. Thermostat, 110vac Dayton 2E369	HMS	7	OPEN, 110vac applied	4	> 6.9×10^7
23. Valve, gas, millivolt Dayton 36C21U	HMS	7	CLOSED	4	> 6.9×10^7
24. Valve, gas, 24vac Dayton 36C03	HMS	7	CLOSED	4	> 6.9×10^7

Table V. INCIDENCE OF ITEM MALFUNCTIONS AND REPAIRS, ALL EXPOSURES

	ITEM	MANUFACTURER/ MARKETER	MODEL NO.	NUMBER OF EXPOSURES	MAL-FUNCTIONS	CORRECTED BY	
						VAC ONLY	COMPONENT REPLACE
1.	Amplifier, Audio Power	Dynaco	410	12	12	10	2
2.	Calculator/ Printer	Tex. Instr.	SR-56/PC 100	13	0	-	-
3.	Computer, Micro	MOS Tech	KIM-1	9	0	-	-
4.	Computer, Mini	DEC/RDA, Inc.	LSI-11	45	42	41	1
5.	Oven, Microwave	Amana	RR-9	9	5	4	1
6.	Radio, Clock	Panasonic	RC-6010	21	0	-	-
7.	Radio, Port.	Gen. Electric	7-2971	11	0	-	-
8.	Receiver, AM-FM	Onkyo	TX-1500	11	1	1	-
9.	Recorder, Portable	Gen Electric	3-5003-A	14	0	-	-
10.	Recorder, AC or Battery	Superscope/ Marantz	C-104	9	0	-	-

Table V. INCIDENCE OF ITEM MALFUNCTIONS AND REPAIRS, ALL EXPOSURES (CON'T)

ITEM	MANUFACTURER/ MARKETER	MODEL NO.	NUMBER OF EXPOSURES	MAL- FUNCTIONS	CORRECTED BY VAC ONLY	CORRECTED BY COMPONENT REPLACE
11. Register, Cash	National Cash Register	1921-112401	12	0	-	-
12. Stereo System "Compact"	Panasonic	SE1160	11	0	-	-
13. Telecopier	Xerox	400	8	0	-	-
14. Terminal, Telephone	Tex. Instr.	735	5	5	4	1
15. Terminal, Video	Lear Siegler	ADM-3A	9	0	-	-
16. Television, B&W, 16"	Sears	564.50360600	7	0	-	-
17. Television, B&W, 19"	RCA	AC192W	14	7	7	-
18. Television, Color, 19"	RCA	FW497W	29	23	23	-
19. Television, Color, 25"	Sears	564.44580702	12	3	2	-
20. Thermostat, Millivolt	Dayton	2E233	4	0	-	-

Table V. INCIDENCE OF ITEM MALFUNCTIONS AND REPAIRS, ALL EXPOSURES (CON'T)

ITEM	MANUFACTURER/ MARKETER	MODEL NO.	NUMBER OF EXPOSURES	MAL-FUNCTIONS	CORRECTED BY VAC ONLY	CORRECTED BY COMPONENT REPLACE
21. Thermostat, 24 Vac	Honeywell	T87F	4	0	-	-
22. Thermostat, 110 Vac	Dayton	2E369	4	0	-	-
23. Valve, Gas, Millivolt	Dayton	2E380	4	0	-	-
24. Valve, Gas	Dayton	2E402	4	0	-	-
Totals 24 Items Tested 8 Items Malfunctioned 4 Items Required Repairs			281	98	92	6

V. SUMMARY

A sample of 24 electronic and electrical items often found in the home and office have been exposed to carbon fibers until malfunctions developed or exposure levels exceeded 10^7 fibers·second/meter^3. Of the 24 items tested, 8 malfunctioned and 4 of these required repair beyond simple vacuuming.

Three (3) of the eight (8) malfunctioning items had mean exposures greater than 10^7 f·s/m^3 for all fiber lengths.

The items which required the least exposure to produce malfunctions were fan cooled without filters (Computer, LSI-11; Amplifier, Dynaco 410; Terminal, Texas Instruments, Model 735).

Generally, the items had considerably lower mean exposures when exposed to longer fibers than when exposed to short fibers (when comparing $\langle E_0 \rangle$ for the same fiber and item operation mode).

However, one item had a lower mean exposure for a shorter fiber than a longer fiber: the 19" black and white RCA television had a mean exposure for 2-3 millimeter T300 fibers of 4.8×10^7 f·s/m^3 while the mean exposure for 16 millimeter fibers was greater than 6.8×10^7 f·s/m^3. This could be due to statistical flucuations of so few tests but when fiber length exceeds one or both dimensions of the ventilation slot the probability of these long fibers entering convectively cooled item cases is reduced.

APPENDIX A*

Derivation of the Maximum Likelihood Estimate of the Mean for an Exponential Failure Distribution

Jill H. Smith

*Extracted from BRL Report No. ARBRL-TR-02205, "Vulnerability Model Validation Testing - Project HAVE NAME (U)", E. M. Vogel and J. H. Smith, December 1979, SECRET.

The exposure to failure distribution for a single fiber kill is

$$F(E) = 1 - e^{-E/\lambda}$$

and therefore has density function

$$f(E) = 1/\lambda e^{-E/\lambda}$$

To obtain the best estimate of the mean, λ, the method of maximum likelihood is used. The likelihood function, L, is the probability of obtaining certain outcomes in a sample and by definition is the product of the density functions.

Therefore, if we have m failures out of n tests, the likelihood function is

$$L = \prod_{i=1}^{m} (1/\lambda e^{-E_i/\lambda}) \prod_{i=m+1}^{n} (e^{-E_i/\lambda})$$

$$= (1/\lambda^m e^{-\sum_{i=1}^{m} E_i/\lambda}) (e^{-\sum_{i=m+1}^{n} E_i/\lambda})$$

$$= (1/\lambda^m e^{-\sum_{i=1}^{n} E_i/\lambda})$$

Maximizing the likelihood function, we find the most likely value for λ, the mean. Maximizing the natural log of the function is equivalent to maximizing the function itself, therefore,

$$\ell(\lambda) = \ln(L) = -m\mathrm{Ln}\ \lambda - \frac{1}{\lambda}\sum_{i=1}^{n} E_i$$

$$\frac{d\ell(\lambda)}{d\lambda} = -\frac{m}{\lambda} + \frac{1}{\lambda^2}\sum_{i=1}^{n} E_i$$

$$0 = \frac{-m}{\hat{\lambda}} + \frac{1}{\hat{\lambda}^2}\sum_{i=1}^{n} E_i$$

$$\hat{\lambda} = \sum_{i=1}^{n} E_i/m$$

The mean exposure to failure, $\hat{E} = \hat{\lambda}$, is therefore the total test exposure divided by the number of failures.

What happens when E is large and the number of failures, m is zero?

$$\lim_{m=o} \hat{\lambda} = \infty$$

$$1 - e^{-E/\hat{\lambda}} = 0 \quad \text{as} \quad \hat{\lambda} \to \infty$$

As we have no failures with which to estimate the parameter λ we can only say we have less than one (< 1) failure and therefore

$$\hat{E} = \sum_{i=1}^{n} E_i/<1$$

$$\hat{E} = \sum_{i=1}^{n} E_i$$

Confidence Limits for the Exposure to Failure

$$2m \frac{\hat{E}}{\bar{E}} \sim \chi^2 (2m) \text{ where all tests result in a failure.}$$

Thus, it follows that

$$P\left\{\chi^2_{\alpha/2} (2m) \leq \frac{2m\hat{E}}{\bar{E}} \leq \chi_{1-\alpha/2} (2m)\right\} = 1-\alpha$$

where χ^2_α is the $100\alpha^{th}$ percentile of the χ^2 distribution. Therefore,

$$P\left\{\frac{2m\hat{E}}{\chi_{1-\alpha/2} (2m)} \leq \bar{E} \leq \frac{2m\hat{E}}{\chi^2_{\alpha/2} (2m)}\right\} = 1-\alpha$$

The interval $\frac{2m\hat{E}}{\chi_{1-\alpha/2}(2m)}$ to $\frac{2m\hat{E}}{\chi^2_{\alpha/2} (2m)}$ covers the true mean

exposure to failure, $\bar{E}$, with probability $1-\alpha$.

When there is at least one test that does not fail and we truncate on exposure, we have the conservative two sided confidence interval

$$P\left\{\chi^2_{\alpha/2} (2m) < \frac{2m\hat{E}}{\bar{E}} < \chi^2_{1-\alpha/2} (2m+2)\right\} = 1-\alpha \qquad [3]$$

That is,

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}(2m+2)} < \bar{E} < \frac{2m\hat{E}}{\chi^2_{\alpha/2} (2m)}\right\} = 1-\alpha$$

And in the case where there are no failures, m=0, we can conservatively say that

$$P\left\{\bar{E} > \frac{2\hat{E}}{\chi^2_{1-\alpha}(2)}\right\} > 1-\alpha$$

Examples

Applying the above methodology to example data, we compute the point estimates of the exposures to failure and then use the point estimate to construct the confidence limits for the exposures to failure.

The same values of E_i are used in each example to illustrate the effect of "no malfunction" (runs that did not fail), on $\hat{E}$.

Example 1.

Item A is tested five (5) times and malfunctions (fails) every time at the E_i shown.

Test Number	E_i (fs/m^3)
1	1×10^6
2	1×10^7
3	5×10^6
4	5×10^6
5	8×10^6
n = 5	m = 5

$$\hat{E} = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{5}$$

$$\hat{E} = 5.8 \times 10^6 \text{ fs/m}^3$$

Using this point estimate for the exposure to failure, we construct the confidence bounds for the true exposure to failure.

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}\ 2m} \leq \bar{E} \leq \frac{2m\hat{E}}{\chi^2_{\alpha/2}\ 2m}\right\} = 1-\alpha$$

Substituting, we have

$$P\left\{\frac{(10)(5.8 \times 10^6)}{20.48} \leq \bar{E} \leq \frac{(10)(5.8 \times 10^6)}{3.25}\right\} = 0.95$$

$$P\{2.83 \times 10^6 \leq \bar{E} \leq 1.78 \times 10^7\} = 0.95$$

Therefore the interval 2.83×10^6 to 1.78×10^7 fs/m^3 will cover the true exposure to failure, $\bar{E}$, with probability .95.

Example 2

Item B is tested five (5) times and malfunctions on three (3) tests. On the two tests where there were no malfunctions, the tests were terminated at the E_i shown

Test Number	E_i (fs/m^3)	
1	1×10^6	
2	1×10^7	no malfunction
3	5×10^6	
4	5×10^6	
5	8×10^6	no malfunction
n = 5	m = 3	

$$\hat{E} = \frac{\sum_{i=1}^{n} E_i}{m} = \frac{2.9 \times 10^7}{3}$$

$$\hat{E} = 9.7 \times 10^6 \text{ fs/m}^3$$

Using this point estimate for the exposure to failure, we construct the confidence bounds for the true exposure to failure.

$$P\left\{\frac{2m\hat{E}}{\chi^2_{1-\alpha/2}\ (2m+2)} < \bar{E} < \frac{2m\hat{E}}{\chi^2_{\alpha/2}\ 2m}\right\} = 1-\alpha$$

Substituting, we have

$$P\left\{\frac{6(9.7 \times 10^6)}{17.53} \leq \bar{E} \leq \frac{6(9.7 \times 10^6)}{1.24}\right\} = 0.95$$

$$P\{3.32 \times 10^6 \leq \bar{E} \leq 4.69 \times 10^7\} = 0.95$$

That is, the interval 3.32×10^6 to 4.69×10^7 fs/m^3 covers the true exposure to failure with probability .95.

Example 3

Item C is tested five (5) times and does not malfunction (fail) on any test. The tests were terminated at the E_i shown

Test Number	E_i(fs/m^3)	
1	1×10^6	no malfunction
2	1×10^7	no malfunction
3	5×10^6	no malfunction
4	5×10^6	no malfunction
5	8×10^6	no malfunction
n = 5	m = 0	

$$\hat{E} > \sum_{i=1}^{n} E_i = 2.9 \times 10^7$$

Using this point estimate for the exposure to failure, we construct a conservative (as though there was one failure) one-sided confidence bound.

$$P\left\{\bar{E} > \frac{2\hat{E}}{\chi^2_{1-\alpha}(2)}\right\} > 1-\alpha$$

That is $\bar{E} > 9.69 \times 10^6$ with at least 95% probability.

APPENDIX B

TEST NOTES SPECIFIC TO ITEMS

Item: 1. Amplifier, Audio Power
Manufacturer: DYNACO
Model #: 410
Serial #: 41750818
Year Purchased: 1978
Selection Rationale: *Likely to fail*

A. Power Required 11 amps maximum, 120 Vac

B. Ventilation - Fan

1. Fan (in blowing) mounted in center of bottom.
2. Bottom is about one centimeter above table top.
3. No filtering.

C. Location/Configuration as Tested Table top.

D. Operating Mode

1. Input - 1000 Hertz sine wave each channel.
2. Output - 48 Vac to light bulb loads.
3. Power - ∿35 watts each channel.

E. Monitor Points

1. +70 V power supply.
2. -70 V power supply.
3. Output voltage right channel.
4. Output voltage left channel.

The 70 volt DC power supply voltages did not decrease during the runs.

F. Malfunction Criterion Output voltage decrease of 30% or more sustained for 10 seconds -- on either channel.

G. Malfunctions Observed Complete or partial loss of output voltage one or both channels.

H. Repairs

1. After Run 665.

a. The malfunction on Run 665 involved the right channel going down to 0 volts output and also a decrease on the left channel down to 75%.

b. Several vacuum cleanings did not bring the right channel back up. Finally the right channel recovered but during the cleanings a fiber may have affected the left channel. Left channel then read full dc output (72 Vdc).

c. Left channel was repaired by replacing resistors (R13, R14, R15, R22).

2. <u>After Run 670</u>.

a. Malfunction on Run 670 involved the left channel going to 0.

b. The left channel board (PC-28) was replaced but this did not correct the problem.

c. Subsequently, the power output transistors (Q101, 102, 103 and 104) were found to be shorted (and the cause of misleading readings of components on PC-28). Replacing the transistors brought the channel back up.

Item: 2. Calculator with Printer
Manufacturer: Texas Instruments
Model #: SR56 with PC 100
Serial #: 165526 (SR56) & 1029232 (PC100)
Year Purchased: 1977
Selection Rationale: *Many Dollars Invested*

A. Power Required 0.35 Amps, 120 Vac

B. Ventilation - Convective

1. Calculator - no vents.

2. Printer

   a. Slots (30), top, 1.5 x 44 mm each.

   b. Slots (9), bottom, ~1 x 35 mm each - backed by screen below.

   c. Screen with ~1.5 mm diameter holes behind bottom slots.

C. Operation Mode Calculator is in a loop program which counts up and compares x to number in t register. Whenever x=t, 1000 is added to t and counting continues. The PC 100 prints whenever x=t, that is "1000","2000", and "3000" are printed. The printed numbers appear in time 1000 seconds apart. If the calculator-printer would have malfunctioned, the stop time could have been bracketed from the printer tape.

D. Malfunction Criterion Halt in program.

E. Malfunctions Observed None

Item: 3. Computer, Micro
Manufacturer: MOS Technology, Inc.
Model: KIM-1
Serial #: PA 6522
Year Purchased: 1978
Selection Rationale: *Generic*

A. Power Required 6 watts (5VDC, 1.2A).

B. Ventilation - Convective Tested without case.

C. Location/Configuration as Tested Horizontal on table top.

D. Operation Mode

1. Stopwatch - Displays time to hundredths of a second up to 99 min, 59.99 seconds.

2. Post Run - Programmed a second time with cassette recorder.

E. Monitor Points - LED display of time - a mechanical stopwatch is started with the KIM-1 stopwatch.

F. Malfunction Criteria

1. Loss of synchronization between the watches.

2. Post run failure to accept program.

G. Malfunctions Observed None

Item: 4. Computer, Mini
Manufacturer: DEC, Inc components
configured by RDA, Inc.
Model: LSI-11
Serial #: None
Year Purchased: 1977
Selection Rationale: *Likely to Fail*

A. Power Required Not stated - estimate 80-200 watts (fused at 3 Amps)

B. Ventilation - Fans (2) (no filters)

1. One fan blows in across horizontal circuit boards.

2. The second fan blows out through an interior channel formed by the unit walls and power supply heat sinks.

C. Location/Configuration as Tested Chamber floor with stovepipe elbow to in-blowing fan. One ball detector was mounted inside the pipe.

D. Operation Mode Diagnostic Program - Memory Exercisor - Loop Program checks memory and indicates error or halts [MAINDEC - 11 - DZKMA, DEC, Inc.]

E. Monitor Points

1. +5 V power supply.

2. +12 V power supply

3. +5 V and + 12 V power supply comparitor.

4. BDCOK (power status).

5. Processor Halt.

6. Teletype diagnostic program.

F. Malfunction Criterion Halt in program.

G. Malfunctions Observed

1. Halt, recovered - computer halted but started and resumed after start instruction.

2. Halt, no recovery - computer halted and would not start again.

H. Repairs None

Item: 5. Oven, Microwave
Manufacturer: Amana
Model: "Radarange" RR-9
Serial #: 052703504
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 1450 watts, 120 Vac.

B. Ventilation - Fan (no filter)

1. Fan is located on inner cooking cavity and blows into it by way of microwave input wave guide. Fan is inside outer case which is then at negative pressure.

2. Air enters outer case mostly through holes in bottom center - 132 holes, 9 millimeters diameter each.

3. Bottom is about 1 centimeter above the table top.

C. Location/Configuration as Tested Table Top

D. Operation Modes

1. OFF, clock on. After exposure, a jar of water is heated on "HI" power for 2 minutes 11 seconds. The temperature change is measured.

2. ON & OFF, Activated during exposure. While the oven is being exposed it is operated on "HI" for 2 minutes and 11 seconds - heating a jar of water. This operates the fan while the oven is surrounded by airborne carbon fibers.

3. ON, Low power - "warming", Fan on. The oven operates continuously during exposure in its lowest output setting. (We can hear the oven cycling power to the magnetron on about 1 second cycle by listening to the interference on an AM radio.) A jar of water is slowly heated.

E. Monitor Points

1. Clock/Timer.

2. Thermometer - temperature rise in a jar of water is measured.

3. AM Radio - for low power the power cycling to the magnetron can be heard by the interference it produces on the radio.

4. On Runs 749-51 a voltmeter was placed between the power slide switch which after Run 749, was found to have 110 Vac on it. This chrome slide is normally touched by the finger. (The case was grounded.)

F. Malfunction Criteria

1. Clock/Timer loss of correct display.

2. Failure to take instructions or start.

3. Irregularities in water temperature rise.

4. 110 volts on slide switch voltmeter.

G. Malfunctions Observed

1. Run 748 - The oven was activated during exposure - on the second activation the count down timer jumped from less than 2 minutes to 77 minutes (lengthened cook time).

2. Run 749 - The oven was activated 6 times during exposure and did not show a malfunction. After the run 110 volts a.c. appeared on the power adjust slide switch (chrome). Fibers could be seen burning off between the handle and the case. Shock discovered when adjusting oven with slide.

3. Run 750 - The oven ran continuously during exposure in LO power (warm) which cycles power to the magnetron only a portion of the time ($\sim$0.1 sec/sec). After hearing some "pop" sounds the control cycled power to the magnetron continuously. (Probably the oven went to HI power but this was not checked by measuring water temperature rise.) Post Run - 110 volts on slide switch after sliding. The switch was not moved during the run.

4. Run 751 - The oven operated continuously during exposure in LO power ("warm"). The count down timer stopped and could not be re-started by the controls. During clean-up, the controls would not display normally and the high voltage transformer burned out during trouble shooting.

H. Repairs

1. After Run 750 - After vacuuming the inside a thermal protector burned out on applying power to the oven.

2. After Run 751 - The high voltage transformer was replaced.

Item: 6. Radio, Clock
Manufacturer: Panasonic
Model: RC-6010
Serial #: 031404
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 4 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (~40), horizontal on bottom, about 8mm above table top, surrounded on 3 sides by supporting edges. Slot dimension ~2 x 12mm.

2. Slots (~18), vertical on back. Slot dimension ~2 x 10mm.

C. Malfunction Criterion Any deterioration of audio.

D. Malfunction Observed None

Item: 7. Radio, 10 Band Portable
Manufacturer: General Electric
Model: 7-2971A
Serial #: 013848
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 3 watts, 9 Vac (6 "D" Batteries).

B. Ventilation - Convective Slots backed by filter-like material with openings < 1mm.

C. Operation Modes

1. FM.

2. Off.

D. Malfunction Criterion Loss audio.

E. Malfunctions Observed None - (Sometime after the exposures, the radio volume would not get loud enough).

Item: 8. Receiver, Stereo
Manufacturer: Onkyo
Model: TX1500
Serial #: 27114043
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 70 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (360), top, 1.5 x 22mm.

2. Slots (72), bottom, 3 x 30mm.

3. Slots (6), back, 3 x 40mm.

4. Bottom is about one centimeter above the table top.

C. Location/Configuration as Tested Table top.

D. Operation Mode FM Stereo.

E. Monitor Points Speaker Output.

F. Malfunction Criterion Loss of audio.

G. Malfunctions Observed Loss of audio.

H. Repairs None.

Item: 9. Recorder, Battery Powered
Manufacturer: General Electric
Model: 3-5003-A
Serial #: None
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required Not stated. 6 Vdc (4 "C" Batteries).

B. Ventilation - Convective

1. Slots (160), bottom, ~1 x 3mm each.

2. Bottom is about 3mm above table top.

C. Location/Configuration as Tested Table top.

D. Operation Modes

1. The unit records for 30 minutes starting with exposure.

2. The recorder then goes OFF for the rest of the run.

3. Post Run -- The recorded tape is played back.

E. Monitor Point Speaker

F. Malfunction Criterion Deterioration in recording or playback.

G. Malfunctions Observed None

Item: 10. Recorder
Manufacturer: Marantz/Superscope
Model: C-104
Serial #: U260006
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 6 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (~80), bottom, semicircular about 1mm opening on 6mm diameter circle.

2. Bottom is about 2mm above table.

C. Location/Configuration as Tested Table top.

D. Operation Modes

1. The unit records for 30 minutes starting with exposure.

2. The recorder then goes OFF for the rest of the run.

3. Post Run -- The recorded tape is played back.

E. Monitor Point Speaker

F. Malfunction Criterion Deterioration in recording or playback.

G. Malfunctions Observed None

Item: 11. Register, Cash
Manufacturer: National Cash Register
Model: 1921 - 112401
Serial #: 32-11202998
Year Purchased: 1978
Selection Rationale: *Generic*

A. Power Required 120 watts, 1.4 Amps, 120 Vac.

B. Ventilation - Convective

1. Slots (13), 8 x 200mm, with screen on top and side. Screen openings ∿1mm.

2. Slots (~90), 6 x 15mm, around 3 sides (recessed 1 cm from case sides).

C. Operation Modes

1. ON -- Costs entered and register ready to calculate total. Date programmed. Post Run - Transaction completed and additional calculations performed to check operation.

2. ON/Memory -- Several types of transactions (cash, charge) completed with totals stored in memory. Date programmed. Totals read before run. Post Run - Totals compared by printing out tape.

3. Overnight Standby -- Machine is normally left in this mode when not in use. AC power sustains memory, printer motor does not run.

D. Malfunction Criteria

1. Memory loss of entered costs or totals, date, etc.

2. Failure to perform additional calculations after the run.

E. Malfunction Observed None

Item: 12. Stereo System, "Compact"
Manufacturer: Panosonic
Model: SE1160
Serial #: 7L810 094890
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 40 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (3), bottom, 6 x 20mm.
2. Holes (3), bottom, 8mm diameter.
3. Bottom is 6mm above table top.

C. Location/Configuration as Tested Table top,

D. Operation Modes

1. FM Stereo all exposures.
2. Post Run - Check other switch - selectable operation modes.

E. Monitor Points Speakers.

F. Malfunction Criterion Loss of audio.

G. Malfunction Observed None

Item: 13. Telecopier
Manufacturer: Xerox
Model: 400
Serial #: 017759
Year Purchased: 1978
Selection Rationale: *Generic (Assumed)*

A. Power Required 60 watts (not in operation for testing); 120 Vac.

B. Ventilation - Convective

1. Slots (70) vertical front and back. Slot dimension ∿3 x 30mm.

2. Slot (1), top, ∿5 x 350mm.

C. Operation Modes

1. OFF during exposure (unit is almost always found in OFF mode).

2. Post exposure a written page was scanned through in "self test" mode to check operation.

D. Malfunction Criterion Failure to copy written text in "self test" mode.

E. Malfunction Observed None

Item: 14. Terminal, Electronic Data via Telephone
Manufacturer: Texas Instruments, Inc.
Model: 735
Serial #: 007621
Year Purchased: 1976
Selection Rationale: *Generic*

A. Power Required 300 watts maximum, 115 Vac.

B. Ventilation - Fan (no filter)

1. The fan is located on an inner metal case which houses about 70% of the terminals electronics.

2. The outer plastic case has 48 side slots each measuring ∿3 x 62mm.

C. Location/Configuration as Tested

1. Table top.

2. Telephone in chamber.

3. A rubber glove allows keying the terminal while it is being exposed.

D. Operation Mode The unit is ON during exposure and the keyboard is activated frequently. Lengthy key sequences call up an alpha numeric sequence, time, etc., from the remote BRL computer memory.

E. Monitor Points The terminal prints after each keying of the address.

F. Malfunction Criterion Failure to display alphanumerics, time, etc., following keying in.

G. Malfunctions Observed

1. Run 738 - Would not print information stored in remote computer.

2. Run 740 - Loss of carrier line to BRL computer.

3. Run 741 - Random printing.

H. Repairs

1. After Run 742, replaced power module, mother board, and power motor driver assembly (repair cost $400. Repaired by Texas Instruments, Inc.)

2. Also, three locations of partially blown off conductor on PC board were found. These still appeared adequate to conduct. (Loud capacitor discharge sounds were heard during and after exposure).

Item: 15. Terminal, Computer Video
Manufacturer: Lear Siegler, Inc.
Model: ADM-3A
Serial #: K 2564
Year Purchased: 1977
Selection Rationale: *Generic*

A. Power Required 80 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (24), top, 6 x 62mm each backed by screen with 1mm opening.

2. Slots bottom (2), 24 x 250mm each.

3. Bottom is about 2 centimeters above the table.

C. Location/Configuration as Tested Table top.

D. Operation Modes

1. A computer was programmed to display alphanumerics and other display characters on the ADM-3A screen.

2. All characters were continuously written and each pass was numbered.

E. Monitor Points CRT.

F. Malfunction Criterion Failure to display sequence of characters.

G. Malfunction Observed None

Item: 16. Television, B&W, 16"
Manufacturer: Sears
Model: 564.50360600
Serial #: 67215859
Year Purchased: 1977
Selection Rationale: *Many Dollars Invested*

A. Power Required 55 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (140), back, 45° to horizontal, 2 x 40mm each.

2. Slots (300), bottom, 2 x 40mm each.

C. Location/Configuration as Tested Table top.

D. Operation Modes

1. ON

2. OFF

3. ON, with back cover removed to simulate conditions of exposure of a TV on an assembly line.

E. Monitor Points

1. CRT.

2. Speakers.

F. Malfunction Criteria

1. Loss of audio for several seconds.

2. Loss of video for several seconds.

G. Malfunction Observed None

Item 17. Television, B&W, 19"
Manufacturer: RCA
Model: AC 192W
Serial #: 817313034
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 57 watts, 120 Vac.

B. Ventilation - Convective

1. Slots (200), horizontal on bottom. Bottom about 10mm above table top, and surrounded on 3 sides by supports. Slot dimensions ∿3 x 35mm.

2. Slots (~200), nearly vertical, at the upper back. Slot dimensions ∿3 x 35mm.

C. Locations/Configurations as Tested Table top.

D. Malfunction Criteria

1. Loss of video for several seconds.

2. Loss of audio for several seconds.

E. Malfunctions Observed

1. "Loss Vertical Deflection" - Picture shrinks to horizontal bar [the RCA color TV had the same malfunction].

2. "Blank-off of Audio & Video" - appears to lose power.

F. Repairs None.

Item: 18. Television, Color, 19" portable
Manufacturer: RCA
Model: FB497W
Serial #: 806281364
Year Purchased: 1977
Selection Rationale: *Many Dollars Invested*

A. Power Required 120 watts average, 134 watts maximum, 120 Vac.

B. Ventilation - Convective

1. Slots (~200), bottom, ~2.5 x 40mm each.

2. Slots (~120), upper back, are vertical with some slots 2.5 x 30mm and others ~2.5 x 40mm.

C. Location/Configuration as Tested Table top.

D. Operation Modes

1. ON.

2. ON - with back cover removed to simulate a TV in an assembly line.

E. Monitor Points

1. 27 Vdc bias supply.

2. -40 Vdc bias supply.

3. 210 Vdc bias supply.

4. 150 Vac.

5. 900 Vac.

6. Current, emitter of horizontal drive output transistor.

7. CRT.

8. Speakers.

(Monitor voltages and emitter current did not yield interpretable changes when malfunctions occurred.)

F. Malfunction Criteria

1. Loss of audio for several seconds.

2. Loss of video for several seconds.

G. Malfunctions Observed

1. "Loss Vertical Deflection" - The picture shrunk to a horizontal bar.

2. "Blank-Off" - The audio and video went off completely.

3. "Loss Video" - (Observed only when tested with back off) Picture shrunk to dim colored triangle in center of screen.

H. Repairs None.

Item: 19. Television, Color, 25"
Console
Manufacturer: Sears (Sanyo)
Model: 564.44580702
Serial #: V81440534
Year Purchased: 1978
Selection Rationale: *Many Dollars Invested*

A. Power Required 155 watts, 120 Vac.

B. Ventilation - Convective

1. Holes (~1400), back, vertical, ~4mm diameter each.
2. Slots (9), bottom, 7 x 450mm each.
3. Sides go to floor on three sides.

C. Malfunction Criterion Loss of audio or video lasting several seconds. (On Run 683 a burned resistor was found and judged a malfunction although no loss of function had occurred).

D. Monitor Points

1. CRT.
2. Speakers.

E. Malfunctions Observed

1. Run 683 - Burned resistor.
2. Run 685 - Blue gun full on - appeared post run.
3. Run 688 - Horizontal control - appeared about 1-1/2 hours after vacuuming the outside of the TV (pre-Run 689).

F. Repairs After Run 683 - Resistor replaced.

Item: 20. Thermostat, Millivolt
Manufacturer: Dayton Electric, Inc.
Model: 2E233
Serial #: None
Year Purchased: 1977
Selection Rationale: Generic

A. Power Required None - Thermostat switches 750 millivolts at set temperature.

B. Ventilation - None to electrical connections.

C. Location/Configurations as Tested On board in 50 ft/minute airflow.

D. Operation Mode 750 millivolts applied, Temperature control set to OFF.

E. Monitor Points Output connection.

F. Malfunction Criterion Appearance of output voltage with temperature control set to off.

G. Malfunctions Observed None

Item: 21. Thermostat, 24 Vac
Manufacturer: Honeywell
Model: T87F
Serial #: None
Year Purchased: 1977
Selection Rationale: *Generic*

A. Power Required None - Thermostat switches 24 Vac at set temperature.

B. Ventilation Vents allow air to thermostat element.

C. Location/Configuration as Tested On board in 50 ft/minute airflow.

D. Operation Mode 24 Vac applied to Thermostat. Temperature control to OFF (open).

E. Monitor Points Output connections.

F. Malfunction Criterion Appearance of voltage on o tput.

G. Malfunctions Observed None

Item: 22. Thermostat, 120 Vac
Manufacturer: Dayton Electric, Inc.
Model: 2E369
Serial #: None
Year Purchased: 1977
Selection Rationale: *Generic*

A. Power Required None - Switches 120 Vac (14 amperes inductive) at set temperature.

B. Ventilation

1. Slot (1), side, ∿3 x 31mm.

2. Slot (1), top, 3 x 48mm has protruding adjusting wheel (∿1 x 38mm).

C. Location/Configuration as Tested On board in 50 ft/minute airflow.

D. Operation Mode 120 Vac applied. Thermostat set OFF (open).

E. Monitor Points Output voltage connections.

F. Malfunction Criterion Voltage appearing on output.

G. Malfunctions Observed None

Item: 23. Valve, gas burner, millivolt
Manufacturer: Dayton Electric, Inc.
Model: 36C21PU Type 201
Serial #: None
Year Purchased: 1977
Selection Rationale: *Generic*

A. Power Required Negligible - activated by 750 millivolt thermostat.

B. Ventilation None except activation terminals on outside of casting.

C. Location/Configuration as Tested On board in 50 ft/minute airflow.

D. Operation Mode Closed - connected to thermostat (2E233) which was simultaneously exposed.

E. Monitor Points Activation connectors.

F. Malfunction Criterion Voltage on connectors - (sufficient voltage would open the valve).

G. Malfunctions Observed None

Item: 24. Valve, gas burner, 24 Vac
Manufacturer: Dayton Electric, Inc.
Model: 36C03 Type 409
Serial #: None
Year Purchased: 1977
Selection Rationale: *Generic*

A. Power Required 24 Vac, 0.23 amps to activate.

B. Ventilation None except connectors for 24 Vac on outside of casting.

C. Location/Configuration as Tested On board in 50 ft/minute airflow.

D. Operation Mode Closed - connected to thermostat which was simultaneously exposed.

E. Monitor Points Connectors, activation.

F. Malfunction Criterion Appearance of voltage on activation connectors.

G. Malfunctions Observed None.

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